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UNITED STATES BUREAU OF MINES
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AN INTERNATIONAL VIEWPOINT ON SAFEGUARDING ELECTRICAL EQUIPMENT USED IN GASSY MINES

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AN INTERNATIONAL VIEWPOINT ON SAFEGUARDING ELECTRICAL EQUIPMENT USED IN GASSY MINES[1]

By L. C. Ilsley,[2] E. J. Gleim,[3] F. Craven[4]

Electrical apparatus and circuits began to be used in mines about 50 years ago. A search of the literature on mining reveals that in 1882, pumping was being done by electricity in some mines of England. One account tells of a small electric locomotive being used in 1882 "to drive eight corves loaded with coal" in a mine near Dresden. In an account of his visit to some English mines, an American in 1892 mentions that he saw underground electric signals, lights, pumps, hoists, and one revolving-cutter-bar longwall mining machine. Among the early electrical installations in the United States was an electric locomotive in the Lykens Valley Coal Co. mine at Lykens Valley, Pa., in 1887. In 1889 the Sperry electric coal digger was being tried out. Three mining machines were placed in the Prospect mine, East Palestine, Ohio, in 1890. An electrical pumping plant was put in operation during 1892 in the Woodward mine of the Delaware, Lackawanna & Western Railroad Co.

Almost coincident with the proposed use of this new servant in underground workings came the thought of making it safe in gassy mines. Thus we find an account of a design for a protected stationary electric mine lamp proposed by Edison in 1881. Enclosed-type motors were developed in the United States and shipped to English collieries about 1903. From those early beginnings there has been continuous progress until to-day one finds hundreds of pieces of specially designed electrical apparatus distributed in American coal mines and in mines of nearly all important coal-producing countries.

Along with introduction of this equipment grew the idea of the necessity of government aid in standardization. In most coal-mining countries to-day the governments either directly or indirectly have a considerable influence in guiding the design of electrical equipment intended for use in gassy mines.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6690."

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In the United States the Government's activities were represented by a "standard" covering the construction and test of explosionproof motors, which was drafted in 1911 by the Bureau of Mines. This was first published as Schedule 2 in January, 1912. Several revisions, of which Schedule 2C is the current standard, have been issued. Other schedules covering electric cap lamps, telephones, storage-battery locomotives and various other types of equipment followed Schedule 2.

Without going into excessive detail, a comparison will be made of some of the essential requirements of Great Britain, Belgium, Germany, France, and the United States with respect to mandatory or suggested regulations covering the construction of motors and accessories for mining machines and the other larger types of equipment. These particular countries were chosen because information regarding their requirements was readily available.[5] General conditions regarding electrical equipment in these countries have been discussed in previous papers.[6]

Allowable Pressures

In all of the countries considered, it is assumed that one of the hazards connected with the use of electrical equipment will be the possibility of the ignition of an accumulation of fire damp within explosionproof enclosure in which electrical sparks may occur. A gas-tight compartment which would permit no such accumulation is disregarded as being hardly practicable.

In Great Britain and the United States the ability to resist internal explosions of the most violently explosive mixtures of fire damp and air, or of natural gas and air, respectively, is the principal requirement regarding pressures. In the United States an additional restriction is that the pressure developed within the casing as a result of such an internal explosion shall not exceed 150 pounds per square inch.[7]

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[5] Sources of information on regulations:
Great Britain: Coal Mines Act, 1911; British Standard Specifications 270 (1930) and 279 (1927).
Belgium: Institut National Des Mines.
Germany: Verband Deutscher Electrotechniker.
France: Station d'Essais du Comite Central des Houilleres de France.
United States: U. S. Bureau of Mines Schedule 2C.

[6] Ilsley, L. C., Safeguarding electrical equipment used in gassy mines - European practice: I - Great Britain, Information Circular 6082, Bureau of Mines, 1928, 12 pp.; II - Belgium, Information Circular 6135, Bureau of Mines, 1929, 8 pp.; III - Germany, Information Circular 6143, Bureau of Mines, 1929, 15 pp.; IV - France, Information Circular 6146, Bureau of Mines, 1929, 9 pp.

[7] Pressures herein stated are gage pressures.

In Belgium, France, and Germany for totally enclosed compartments there are arbitrary pressure values, graduated according to the internal volume of the casings, which the compartments must be designed to withstand. For casings having an internal volume of more than 120 cubic inches the German and Belgian regulations require the compartment to withstand a pressure of about 114 pounds per square inch, while in France the figure is 171 pounds per square inch. Compartments with a content of less than 120 cubic inches must withstand 114 pounds per square inch to comply with the French requirements, and 85 pounds per square inch for both the Belgian and the German rules. The Germans include another subdivision which applies to casings having an internal volume of less than 30 cubic inches. Such compartments must withstand pressures of 45 pounds per square inch.

Belgium has a further classification embodying enclosures with protected openings or open joints, as distinguished from totally enclosed casings, for which the requirements merely prescribe that the compartments resist the pressures produced by the explosion of a 10 per cent (by volume) methane-air mixture.

In France, enclosures with flange release (that is, flanges designed to permit pressure relief by means of small gaps between the flange surfaces) must withstand a pressure of about 114 pounds per square inch with the flange vents obstructed. For storage-battery casings, it is required that they be sufficiently strong to undergo a pressure of 1-1/2 times the maximum pressure obtainable as the result of the explosion of a fire damp-air mixture (or of a hydrogen-air mixture, in the case of alkaline batteries) within the casing when all its openings are stopped off.

A superficial comparison of the attitudes respecting pressures would seem to indicate that the use of arbitrary pressure requirements (considering that the maximum explosion pressure within compartments is usually less than 100 pounds per square inch) would provide a greater factor of safety for large compartments than the system whereby the compartment merely has to stand up under the explosion tests. On the other hand, particularly in the United States, a large number of explosion tests using the most violently explosive gas mixture is made upon each design of casing. Compartments which can endure this repeatod succession of "shock" loads would, in general, have little difficulty in passing the static pressure requirements of the countries which have established such regulations. Hence, practically, the two systems do not entail any widely divergent results.

In demanding that the battery containers of storage-battery locomotives be made explosionproof, the French and Germans are at variance with the practice in the United States. Because of the presence of hydrogen in the gases evolved from the battery, the explosion to be protected against would be much more severe than that resulting from a simple fire damp-air mixture. The situation is complicated further in that the enclosure of the batteries would hamper any ventilation which would tend to dilute the mixture arising from the battery. With proper ventilation, accumulation of gas in explosive proportions would hardly ever occur within the battery box. An explosionproof enclosure would, by preventing such ventilation, virtually assure the presence of a violently explosive hydrogen mixture within the casing. A battery box built to meet such a possibility might, by its prohibitive bulk and cost, eliminate storage battery locomotive haulage from the consideration of operating officials.

If safe storage-battery locomotives are to be more than mere theoretical possibilities, it is almost imperative to abandon the thought of making the battery containers explosionproof--at least for the capacities requires in the United States. By the exercise of a few simple precautions in the design, it is possible to make a battery box and to assemble the batteries within it in such a manner that the hazard of an ignition originating within the box is remote under normal operating conditions. That the adoption of this stand, which emphasizes the prevention of the ignition rather than a cure of its consequences, is justifiable would seem to be attested to by the excellent records which have been made by the many permissible-type locomotives in service in the United States.

Flanges

For the larger sizes of totally enclosed compartments the rules are in general agreement that the width of joint for ordinary flanges shall be not less than 1 inch. This constitutes the only British regulation covering flange width. The German rules permit flanges of 0.6-inch width for compartments under 120 cubic inches in internal volume and of 0.32 inch for compartments less than 30 cubic inches in internal volume. The United States allows flanges of 0.75-inch width to be used on compartments having an internal unoccupied volume of less than 60 cubic inches. Belgium has a detailed requirement for flat joints fitting one within the other which states that the depth of the fit must be at least 0.4 inch and that the play between the fitting surfaces must not exceed 0.01 inch.

All the countries except the United States have specific provisions for vented flanges. The gap between flange surfaces must not exceed 0.02 inch in Belgium, France, and Great Britain. Germany allows but 0.01 inch separation for ordinary flanges and 0.02 inch for flanges used in conjunction with sliding or hinged covers. For simple vented flanges the minimum width is 2 inches in Belgium, 1.6 inches in France, and 1 inch in Great Britain and in Germany. The width of flange used with sliding or hinged covers in Germany must be at least 2 inches. The French regulations prohibit the use of vented flanges for alkaline battery enclosures.

Closely allied to the subject of flange widths is the question of the allowable distance from the interior of the compartment to the edges of bolt holes. The principal reason for having any requirements on this phase of construction lies in the possibility that a bolt might be omitted or that a flame discharge might take a course out along the bolt. In the United States it is recommended that the distance be at least 0.44 inch; less than 0.25 inch is not acceptable. Belgium, France, Great Britain and Germany all specify a minimum distance of 0.4 inch for ordinary totally enclosed compartments. Germany permits 0.32 inch only on compartments of less than 120 cubic inches of volume where the flange width is less than 1 inch. France and Great Britain require that the distance between the bolt hole and the inside edge of the flange shall be at least 1 inch when vented flanges are used. Great Britain allows the option of making the joint metal-to-metal for a distance of 0.375 inch around the bolts used with the vented flange.

There is a universal attempt to discourage the use of gaskets or packing materials in the construction of flange joints. Belgian rules state that rubber, asbestos, or other jointing materials of small mechanical strength are forbidden except for joints with a fitting section. Plastic joints are permitted by France only for closing cavities containing oil or for bulbs or sight holes of glass. Great Britain and Germany prohibit the use of rubber, asbestos, or of any material liable to deteriorate or disintegrate. The United States permits gaskets, if adequate, only for seating glass in headlight and meter enclosures and does not consider rubber, putty, and plaster of Paris acceptable for this purpose. Germany and the United States prohibit the use of paint on flange surfaces.

The foregoing summary indicates that with respect to flanges, practically all the designs approved by the United States Bureau of Mines would meet the requirements of all the other nations. The class of equipment having an unoccupied internal volume of less than 60 cubic inches for which the United States permits a flange width of 0.75 inch would not comply with the minimum requirements of any country except Germany. Since this class of small apparatus is limited in number, only a few compartments would be affected. The Belgian requirements for "fitted section" flanges are not very explicit. Most flanges of this kind used on apparatus in the United States would meet the requirement for 0.4 inch of width and less than 0.01 inch play. However, some flanges of this type are used in conjunction with plane butt flanges and since the aggregate flange width is considered and must total at least 1 inch in the United States, no special emphasis is laid upon the component parts of the flange. There is quite a number of such flanges which have a fitted section width of less than 0.4 inch. It is not quite clear as to how the Belgians would consider a case of this kind.

In making no provision for vented flanges the framers of the requirements issued by the United States Bureau of Mines were guided by several considerations. One of these was the very doubtful utility of such flanges either for the purpose of relieving explosion pressures or for ventilating the compartments. Another reason may be found in the explosion-test requirements of the United States Bureau of Mines. One of the causes for rejection is the discharge of flame from any joint or opening in a compartment. Most vented flanges would permit such flames to pass through. Although flame discharge from vented openings of the types permitted by the European countries probably would not give rise to any external ignitions, the United States' requirements were formulated to establish an additional factor of safety by considering the mere appearance of flame from a compartment as constituting a failure in the explosion tests.

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This difference between the European and United States test requirements is important. Whereas a compartment would be considered satisfactory with respect to joints if it met the physical dimension and other similar requirements of Belgium, France, Germany, and Great Britain, provided that no external ignition took place upon the explosion tests, in the United States it would have to permit no flame discharge visible to an observer. In the United States several casings which otherwise satisfied the requirements for flange dimensions, et cetera, have been altered as a result of the appearance of flames from the joints during the explosion tests. This requirement establishes an equitable criterion by which the influence of many factors such as bolt placement, stiffness of section, uniformity and quality of machining, and other features may be judged and, if necessary, improved.

Bolts and Bolt Holes

The use of bolt holes passing entirely through the casings of explosion-proof apparatus is not viewed favorably in any of the regulations. France prohibits unbottomed bolt holes for removable bolts. Belgium and Great Britain state that bolt holes through walls are not to be used and Great Britain further specifies that the thickness of wall at the bottom of the bolt hole must be greater than one-third the diameter of the bolt hole, but in no case less than 0.125 inch. The German regulation is that bolts should, as a rule, not pass through the walls of the enclosure but that if they do pass through they must be fixed so that they can only be withdrawn by special means. In the United States all holes which would leave an opening into the enclosures if the bolt or screw were omitted must be bottomed. Studs passing through compartment walls if they are permanently fastened in place, preferably by welding, are considered acceptable. The United States Bureau of Mines permits the following notable exceptions to the rule: It is allowable to have holes through a motor casing for bolts, studs, or screws used to hold pole pieces and brush riggings provided two fastenings are used for each pole piece or brush rigging and provided that (a) the holes in the latter are bottomed or (b) the studs, et cetera, are permanently fastened in the pole pieces and brush rigging or else arranged so as not to be removable from the exterior.

Great Britain has no set requirements for bolts or other means of fastening to be used for the safe assembly of explosionproof enclosures. Belgium and France require that those bolts whose absence might affect safety must be so designed that they can be removed only by a special key. Germany has the latter requirement only for cover bolts but demands that all the bolts for holding an enclosure together be locked in such a way that they do not work loose under operating conditions. The United States specifies that all bolts, nuts, and screws used in fastening flange joints shall be provided with lock washers or other suitable means to prevent loosening; the length of thread on bolts, screws, and studs must permit tightening of the joint even though lock washers are omitted; it is recommended that, unless especially rigid construction is involved, bolt spacings should not exceed 6 inches; bolts, et cetera, should be generously proportioned to minimize stripping of threads and to give adequate strength.

The exceptions in the United States to the general prohibition of through bolt holes were dictated by a desire to hamper the designer as little as possible, and yet to preserve the essential safety of the assembly. It is believed that the qualifying restrictions applied to the use of these through holes accomplish this satisfactorily. Great Britain and the United States have not thought it necessary to require that bolts on covers should be removable only by special tools, as called for by Belgium, France, and Germany. Other features of the regulations in the United States deserve some discussion. The requirement that bolt, screw, or stud thread length be sufficient to permit tightening of the joint even if the lockwasher should be omitted represents a precaution whose merits are obvious. The chief object of the requirement for adequate strength of bolts is to call to mind that in addition to its primary purpose, a fastening must also be strong enough to withstand repeated assembly under severe stress without damage to itself or to working parts.

Practically all direct-current motors approved in the United States have through holes into the casing for either pole piece or brush rigging bolts. Apparently, this would prevent them from meeting the requirements of the other countries which are under consideration in this paper. It would be fairly easy to modify covers, et cetera, to take bolts removable only by special tools. Otherwise foreign requirements for bolts and bolt holes would be satisfied by most American equipment without extensive alteration.

Relief Devices

Considerable detail is given to plate relief (or ring relief) devices in the regulations of Belgium, France, Great Britain and Germany. The maximum allowable width of the gap is 0.02 inch in all these countries. The minimum width of plate is 2 inches in Belgium, France, and Germany; Great Britain requires only 1.5 inch width. The thickness of the plate must be at least 0.08 inch in France, 0.04 inch in Great Britain, and 0.02 inch in Belgium and Germany. Plates liable to corrode must not be used and the entire device must be protected against dirt or damage to comply with the Belgium, British, and German rules. Belgium further requires that the platos be arranged so that the gap will not be increased due to bending of the plates, and that the distance pieces in the gap shall be the same width as the plates. A similar demand that the gap may not increase due to buckling of the plates is included in the German specifications. The Germans also require that the rolief device be removable only by special means. The United States Bureau of Mines, without going into details of construction, groups all special devices for pressure relief, ventilation, or drainage under one head. The test requirement, as with all explosionproof equipment, is that the device shall be capable repeatedly of preventing the passage of flame through to the exterior of the compartment on which it is used and shall not give rise to any dangerous afterburning. Mechanically, the United States requires that the device shall be strong enough so that it may be cleaned and inspected without impairing its effectiveness; it must be securely fastened in place and guarded to prevent mechanical injury and the entrance of foreign material.

Only a few designs of equipment in the United States are provided with pressure-relief devices. Of these, the only type coming under the direct requirements for plate relief devices would fail to meet the European requirements in that the thickness of the plates is less than is permitted in any of the regulations and they are made of ordinary sheet steel which is not protected against rust or corrosion. There are several oil and water drain devices which are used on apparatus approved by the United States Bureau of Mines. The foreign rules do not explicitly mention such devices. If they were not acceptable, the design of practically all the compartments is such that the holes in which these drains fit could be plugged shut and still leave the compartment able to pass the test requirements of the various countries.

In view of the fact that the United States Bureau of Mines has never prohibited pressure-relief devices, it is notable that the totally enclosed design predominates. The few compartments which employ pressure relief devices are used on early designs and the tendency is to discontinue entirely the use of these devices. This trend is due to the fact that it has been found that the advantages arising from the use of the pressure relief devices are not sufficient to compensate for their additional cost and space requirements.

Shafts

One inch of length is the minimum for plain sleeve bearings other than for motor shafts, excepting in France, where the minimum length is 1.6 inch, and in the United States, which has 1 inch as the minimum length for large compartments but also permits a 0.75 inch length on casings having internal unoccupied volumes of less than 60 cubic inches. The allowable side play or diametral clearance is 0.02 inch in France and Great Britain and 0.01 inch in Germany and the United States. Belgium has no set requirements for the diametral clearances of such shafts but its rules state that oiling grooves, if used, must not establish a path from end to end of the bearing and if they are longitudinal they must be at least 0.4 inch apart and discontinuous for at least 0.4 inch.

France and the United States consider motor shafts with sleeve bearings subject to the same requirements as other sleeve bearings, but in Belgium, Great Britain, and Germany, motor shafts in sleeve bearings must comply with special requirements. In these latter countries the length of motor sleeve bearings must be 2 inches. The diametral clearance must be less than 0.02 inch. Belgium states that if the gap between the rotor and stator exceeds 0.02 inch, necessary precautions to eliminate friction between the shaft and the bearings must be taken. Grease boxes must be outside the casing. The oil grooves for motor bearings in Germany must not connect the interior and exterior of the enclosure; they must be spaced at least 0.4 inch apart and longitudinal grooves must be interrupted for a distance of at least 0.4 inch. This requirement also applies to ball and roller type bearings. Great Britain requires that sleeve bearings, unless they comply with the aforementioned regulations for length and clearance, must have an additional sleeve, gland, or labyrinth device sufficient to ensure a flameproof joint. No stuffing boxes or packed joints for shafts are allowed in Great Britain.

For ball and roller bearings, Belgium and France do not add any special regulations. In Great Britain the bearing housings for ball or roller bearings must be constructed so that they have an axial length of not less than 1 inch with a diametral clearance from the shaft of less than 0.02 inch. Germany prescribes that on labyrinth type bushings the total radial gaps shall be at least 2 inches long. Roller and ball bearings used on equipment made to meet United States Bureau of Mines requirements must have a flame path of at least 1 inch in length between shafts and the inner parts of the bearing housing. The diametrical clearance should not be greater than 0.03 inch for this length. The length of any oil grooves or felt rings is not included in the measurement of the length of such paths.

It may be seen that with the exception of plain sleeve bearings on large compartments other than motors, the regulations for equipment in the United States are less rigorous than they are in the other nations which are being compared. Even in this case of plain sleeve bearings, the French requirements call for a greater axial length than those of the United States. Motor bearings in particular, would fall short of meeting the minimums of all the countries being discussed. It would be a fairly simple matter to modify most ball or roller bearing housings to meet the requirements of Great Britain. This would merely entail a reduction to 0.02 inch in diametrical clearance between the shaft and the housing. For the other countries, not only would the clearance have to be reduced, but also a length of 1.6 inches for France and 2 inches for Belgium and Germany would have to be provided.

Plug and Socket Connections

From their regulations, Belgium and France apparently consider plug and socket connections as explosionproof compartments. Belgium requires the socket jacket and plug casing to be of metal and specifies that the length of the joint between the two must be at least 2 inches when the contacts are first made and the play between the surfaces of the joint must be less than 0.01 inch. France cites 1.6-inch length and 0.02-inch play to correspond to these figures. Belgium also requires that there be an interlocking device to prevent the component parts of the plug from becoming alive before assembly and to prevent the removal of the plug when the parts are alive. Germany requires that the plug be constructed so that no sparks can occur when the plug is in operating position, and that the plug be interlocked with an explosion-proof switch in such manner that the insertion of the plug is possible only when the connection is dead. The British Coal Mines Act of 1911 in its discussion of what constitutes a properly constructed connector plug outlines some broad principles. The primary requirement is that the connector plug must be so made that it can be handled at all times without danger. The plug must be built so that a reliable ground connection is automatically made between it and the socket. The plug should include a means for gripping the outside of the cable so as to relieve the terminals of stress. The discussion states that it is advantageous to have plugs used with coal cutters so

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interlocked that the switch can not be turned on until the plug is fully and properly in place and, conversely, it should be impossible to withdraw a plug before the switch has been turned off. The British Standard Specifications go into detail about the physical dimensions of a standard plug and socket to be used for currents up to 100 amperes at 600 volts. These specifications are primarily for the purpose of securing interchangeability of plugs, and aside from providing a notch for an interlock engagement member they do not cover the details of the interlock. It is also required that an operating and retaining device integral with the socket portion be provided to move the plug into and out of the socket and that these operations shall be accomplished only by means of this device.

In the United States a removable plug is not considered, of itself, as an explosionproof casing. In general, it is required that the plug be interlocked so that the plug may neither be inserted nor withdrawn when the receptacle contacts are alive. For "running" plugs on storage-battery locomotives, it is acceptable merely to provide a padlock on the plug to prevent its removal by unauthorized persons. When separate receptacles to permit battery charging are used, the receptacles must be provided with a cover or dummy plug locked in place to prevent access to live terminals while the locomotive is in operation. The latter provision also applies to any receptacle from which power is taken. The cover or dummy plug must be attached to the machine by a chain or its equivalent so that it can not be lost when it is not in use. On machines provided with a socket for receiving energy from a plug on a trailing cable, the plug must be interlocked to prevent its insertion or removal when the machine switch is closed, or else be so designed that it can be inserted or withdrawn without creating the hazard of igniting gas or coal-dust. Such plugs must, in addition, be kept locked in their receptacles to prevent removal by unauthorized persons. Where there is any possibility of strain upon the cable of removable plugs an insulated clamp must be provided to prevent strains upon the plug connections. If, as on plugs supplying power to machines, any terminals are alive while the plug is removed from its socket, the live terminals must be adequately shielded or recessed to prevent accidental grounds or short-circuits while the plug is out of its receptacle.

The detail respecting removable plugs and their sockets is characteristic of the British and American rulings which embrace the actual electrical circuits and their protection. The underlying principles are simple, but the possible combinations to be considered are varied and many of them do not present any clear-cut distinctions which might render a given arrangement either safe or unsafe. Merely to require interlocking so that the plug can not be inserted or removed while the contacts are alive leaves many important hazards unprovided for. The attempt to consider such possible hazards and at the same time to differentiate between plugs which need not be operated at the working face and those which must be, between plugs which furnish power to an equipment and those which receive power, and so forth, constitute some of the problems involved. As to whether the plug-receptacle connection should be judged an explosionproof compartment, it may be said that the design of the contacts on such plugs practically eliminates all possibilities

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of the normal occurrence of sparks at the contacts when the plugs are in place. The very nature of the construction of most plug-receptacle joints which are usually made close fits to secure proper alignment of the contacts would probably render the assembled units explosionproof even though they were not primarily so designed.

Some of the interlocked plug designs permitted in the United States would meet the German requirements. Many of the plugs might be modified rather easily to meet the clearance and flame path length requirements of Belgium and France. The stipulations concerning ground connections and interchangeability would put some difficulty in the way of any attempt to adapt plugs in use on American equipment to British application.

Cable Connections, Lead Entrances

The French regulations seem to have no specific provisions to cover cable connections or lead entrances. The German rules are very little more detailed. They state that the cable connections shall be sealed and protected in such a manner that they are capable of withstanding the explosion pressure. There is also a German requirement that any terminal boxes wherein live contacts are available must be protected by a suitable cover to provide against hazards from shock or from mechanical blows. Any screw contacts outside explosionproof enclosures must be so safeguarded that a loosening of the screw resulting in poor contacts can not occur. Belgium requires that armored cables be connected to apparatus either by means of a box fastened to the apparatus and filled with insulating material, or by passage directly through the walls of the enclosure through a stuffing box packed with metallic packing. In applying the first method, the leads must be taken through the walls of the enclosure by means of insulated terminal studs securely fixed. The conductors at both ends of the stud must be fastened to it either by soldering or by locked nuts. The cable armor must be secured to the terminal box. For the stuffing-box type, it is required that the metallic sheathing of the cable shall be made fast to the outside of the case in such manner that it carries all the tensile stress on the cable. The lead sheathing of the cable must be exposed, and rolled if necessary, where the cable passes through the stuffing box. The compressed length of packing must be at least 0.48 inch after the gland is packed. The clamp nut of the stuffing box must have at least two complete threads or if a fitted joint is used the length of the fitted joint must be at least 0.48 inch, after the packing has been compressed. For flexible cables, the Belgian rules state that they must be connected to the apparatus in the same way as armored cables and passed after examination.

In Great Britain the requirements call for all terminals of machine windings to be brought to insulated terminals enclosed in a terminal box which must be outside the explosionproof enclosure. Leads external to the machine itself must in no case be exposed. The connections through the wall of the explosionproof compartment must be fitted with flameproof glands or bushings. The terminals must be designed to have adequate insulation and leakage distance between one another and between terminals and case. To minimize heating and arcing, means must be provided for locking the clamping nuts or screws which are used for securing the external conductors to the terminals. Effective means for anchoring cables at their point of entry into

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the terminal box must be provided so that any strain set up in the cable can not be communicated to the terminals. The earthing connection grips used for cables having metallic coverings may be used for this purpose. An electrically efficient external earthing conductor must be furnished so that adequate connection to the earthing conductor may be made irrespective of the means provided for attaching the metallic covering of the cable to the case.

The United States regulations governing electrical connections give a number of options on the manner in which electrical connections may be taken through the walls of compartments. Insulated studs, if used, must be protected against creepage, contact between neighboring terminals or between terminals and ground, loosening, and accidental contact with men or material. For the stuffing-box type of lead entrances, untreated asbestos packing is recommended. The length of compressed packing measured along the cable must be at least 0.5 inch and the width of the space for the packing material must not exceed the diameter of the packing material by more than 50 per cent. Stuffing box nuts or glands must be secured against loosening. It is recommended that insulating bushings should be used in stuffing boxes, especially if the voltage exceeds 250 volts. When outer braid insulation covering is used on wire passing through stuffing boxes, the braid should be of asbestos or slow-burning material. Wires and cables may be taken through openings filled with sealing compound provided that the design of the opening and the composition of the material are such that there will be no tendency for the compound to crack, flow, or be displaced. Wires between adjacent compartments may be led through tubes or bushings which shall be secured against loosening. Such ducts or tubes must terminate wholly within explosionproof enclosures. All wiring, particularly any outside of locked or explosionproof enclosures, must be adequately protected electrically and mechanically. Flexible metal conduit is not acceptable as such protection. Good-grade rubber air hose or its equivalent may be used if rigid conduit is unsuitable. All conduit ends must be adequately clamped or secured.

Effective explosionproof lead entrances may be secured by the proper application of any of the methods given above. In the United States there is an increasing utilization of the stuffing-box type of lead entrances. Coupled with this there is a tendency to eliminate entirely all connections and splices outside explosionproof enclosures so that the leads may be run continuously from compartment to compartment. This system reduces to a minimum the possible sources of trouble due to poor contact, et cetera, outside of explosionproof casings.

With the exception of Great Britain, where earthing requirements and the rule that terminal connections must be brought to a terminal box outside the case would create some difficulties respecting stuffing box lead entrances, little alteration would be required to adapt American lead entrances and connections to foreign requirements. For Belgium, where metallic packing is required in the stuffing-box type of lead entrances, it would be a simple matter merely to substitute the metallic packing for the asbestos generally used in the United States.

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Oil-Immersed Equipment

The German regulations do not permit the use of equipment protected by oil immersion for portable apparatus. Their rules for the construction of oil-immersed apparatus for other applications require that no sparks or flames shall be emitted above the oil surface. Suitable oil-level indicators visible from the outside of the tanks must be provided. The glass for such gages must be thick, securely fixed, and adequately protected from damage. Cover bolts for oil-immersed apparatus should be removable only by special means. Provision must be made for the escape of oil fumes and any vapors obtained during the operation of an oil-immersed switch. Belgium has a requirement that switches must be completely immersed in oil and placed in explosionproof casings. The French regulations do not seem to contain any definite reference to oil-immersed apparatus. The chief mention in the English rules is a statement that the explosion tests shall be carried out with the oil in place.

The regulations of the United States Bureau of Mines make no reference to oil-immersed equipment. In addition to the explosion-test and construction requirements, it would have to be demonstrated that the adequacy of the compartment would be unimpaired by continued use under operating conditions. In the United States there has been little incentive for the development of oil-immersed apparatus for use with portable machinery in gassy mines, because the manufacturers have been able to construct a satisfactory air-break switch and control equipment which is compact enough for ordinary mining machines.

Other Regulations

Some of the countries have miscellaneous rules covering points which do not fall into any definite classifications. A brief listing of a few of these follows.

Belgium requires that any sight holes in the sides of enclosures must be protected with thick double glass, firmly fixed.

In France, the following exceptions are made to the rules which require that all parts of electrical apparatus for use in a fire-damp atmosphere be enclosed in explosionproof casings:

(a) Cavities which have been filled with an insulating mixture in the course of construction and which always remain in this condition.

(b) Windings, without moving contacts, of motors with a maximum development of 50 horsepower, and which are used near pit bottoms of either downcast or upcast shafts, it being understood that these windings are so made that the insulation is in excess of 50 per cent more than the value actually required.

In Germany, alternating-current operating magnets may be used without explosionproof casings provided that automatic devices are used for preventing any excess of heating beyond the permissible value. The same exception is made in the case of metallic resistances so constructed that a temperature not exceeding 200° C. will be obtained under normal conditions. In resistances not in continuous use, special precautions must be taken and automatic devices must be provided to cut out the resistance when the 200°C. temperature is exceeded. Oil-immersed resistances must have special provisions to prevent the temperature at the oil surface from exceeding 100°C. All such resistances must be adequately designed mechanically and electrically and protected against accidental contact and the lodgement of foreign bodies and drip water. All joints in the conductors used in these resistances must be properly soldered or bolted.

The United States requirements recommend that glass-covered sight holes should not be used for motors. It is stated that inspection openings or covers of any nature should be kept to the minimum number necessary for the proper inspection and assembly of parts. Inspection covers not held by bolts or screws must be protected by locks or seals against loosening or tampering by unauthorized persons. The glass in meter and headlight enclosures must be at least 0.5 inch thick. In the construction of fabricated (welded or riveted) casings, it is recommended that sheet steel of less than 0.1875-inch thickness should not be used.

Belgium, France, and Germany, although they have some requirements for the interlocking of fuses and switches, do not devote any attention to the definition of the kind and extent of switching and protection which is required for explosionproof apparatus. It is probable that these countries consider the ordinary standards respecting the protection of equipment in their respective countries to apply.

In Great Britain and the United States, it is required that the electrical protection of explosionproof equipment be especially thorough. To cover the various possibilities, the regulations on this score give rise to many specialized interpretations. Great Britain and the United States require that a means for isolating the apparatus by opening all ungrounded power conductors should be provided readily accessible to the operator of the machine. The British rules consider a manually operated controller or starter, which opens all power conductors except the grounded lead, as satisfactory for this purpose. In the United States, a separate switch or circuit breaker is demanded on all motors of more than 10 horsepower. Portable drills, according to the United States rule, must be provided with a switch at the motor with one pole for each power conductor of the trailing cable. Both Great Britain and the United States require the use of adequate overload protection for all apparatus used in gassy mines. The regulations covering this phase are rather detailed. Their underlying intention is that the apparatus be safeguarded from dangers arising from sustained overloads, short circuits, arcs to ground, or failure of insulation. In Great Britain much emphasis is placed upon the proper earthing of machine frames. Germany also has some mandatory rules regarding grounding of frames. The United States makes compulsory the grounding of drills which are held in the hand or against the body.

With regard to voltage limitations, France and Belgium appear to have no explicit regulations. The British rules permit voltages up to 650 volts for ordinary mining machinery with the exception of portable drills, etc., which must be operated at 250 volts or less. In Germany 500 volts direct current or 250 volts (to ground) alternating current represent the upper limits for all but portable electric motors designed to be held by men. For the latter, more than 250 volts direct current, or 70 volts (to ground) alternating current may not be employed. The United States requirements for explosionproof equipment do not recommend that potentials above 250 volts d.c. or 220 volts a.c. be used, but state that potentials up to 500 volts d.c. or 440 volts a.c. may be approved. The testing engineers of the United States Bureau of Mines have restricted portable drills to the lower bracket of voltages, i.e., 250 volts d.c. or 220 volts a.c.

Automatic protection of equipment when provided by fuses is a subject affording some interesting comparisons. Belgium and France do not mention this matter in their regulations for flameproof equipment. Great Britain requires that fuses, when used, be interlocked so that there may be no danger when renewing the fuse: or else, if the fuse can be replaced in a live circuit, there shall be no danger if the fuse should happen to blow in the act of replacement. The German regulations state that fuse compartments must be combined with explosionproof switch compartments in such a manner that the fuses may be replaced only when they are dead. The United States requires that main fuses shall be interlocked so they can be renewed quickly and conveniently without introducing the hazard of igniting methane or coal-dust mixtures. The speed and facility of renewal are regarded in the United States as vital factors in the safety of the design, since it is believed that convenient provisions for replacement will tend to assure that fuses of proper size will be used. To accomplish this end it is also allowable to use multiple fuses which can be inserted in circuit successively, provided the compartment in which they are contained is locked or sealed. Fuses for portable drills and those for headlight or control circuits may be exempted from the above requirement at the discretion of the testing engineers at the United States Bureau of Mines.

Even with a detailed set of regulations, the officials in each country must continually pass upon many matters which are not incontrovertibly settled by the rules. Nearly all the codes state that devices other than those expressly covered by the rules may be admitted after tests and examinations by the testing officials.

Many other features of the regulations could be discussed. The foregoing points, however, sufficiently illustrate the trends of the rulings in the different countries.

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Discussion

The question naturally arises: "Since the same hazard is being guarded against, why are there so many differences in the details of the rules?" It would have been highly advantageous if standards had been established which would make apparatus built in one country applicable for use in any other country.

The reason for the differences lies primarily in the fact that the codes were formulated by different bodies. The fundamental principles of explosion-proof protection are simple. There was usually close experimental agreement regarding the protection required to just prevent external ignitions under laboratory conditions. When it came to determining what constituted a desirable factor of safety to be superimposed upon these test minima, the various interpretations arose. Each country had its own conditions to confront. Not only were the mines in the separate countries of widely differing character, but the regulatory powers of the bodies sponsoring the codes were no less varied. The extent to which reliance could be placed upon maintenance, discipline, supervision, and other items of like nature entered as important factors into each decision on the rules. The comparisons given in this paper represent a partial resume of the resultant rulings.

Now that an extensive practical background covering a number of years of actual operation of explosionproof electrical equipment is available, it would seem to be desirable to examine the results of this service in order to determine whether the rules have achieved their purpose and whether any changes should be made. One of the goals of such a survey might profitably be the unification of the various codes. However, the presence of many obvious difficulties makes it doubtful that a single standard will soon be attained.

In England and in the United States, where by far the greatest number of explosionproof electrical machines are employed, the records of the machines have been excellent. In both those countries the rulings have undergone minor modifications from time to time but the chief features of the regulations have descended almost intact. Belgium, France, and Germany have probably had the same fortunate experience with their rules. Evidently, then, the codes seem to be working satisfactorily in each country. Under them, there is available a great variety of safe electrical equipment to serve practically any need to which power can be applied underground.

The rules have served to guide an art which is finding increasing utilization in the mining industry. Like most rules, they may be amended for cause. Meanwhile, they are daily functioning as important safeguards protecting the lives of thousands of miners.